Update on Recent Protein Research for Finishing Beef Cattle Fed Steam Flaked Corn-based Diets[1]

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With special acknowledgment to
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P.J. Defoor, and G. C. Duff of
New Mexico State Univ., Clayton Livestock Research Center, Clayton;
L. W. Greene, K. McBride, F. T. McCollum, and J. Vasconcelos of
Texas Agricultural Experiment Station, Amarillo;
M. S. Brown and P. Dew of
West Texas A&M University, Canyon; and
R.W. Todd and R. N. Clark of
USDA-ARS-CPRL, Bushland, TX

Summary:
Seven cooperative experiments were conducted to determine the effects of dietary CP concentration and source on performance, carcass merit, site and extent of digestion, and potential ammonia emissions of finishing beef steers fed steam-flaked corn-based diets. In Experiments 1, 2, and 3, diets were arranged in a 3 x 3 factorial with three CP concentrations (11.5, 13, or 14.5% of DM) and three sources of supplemental CP (N basis): 100% urea (U); 50:50 blend of urea and cottonseed meal (B); or 100% cottonseed meal (C). Steers were initially implanted with Ralgro and reimplanted with Revalor-S on d 56. Two performance studies were conducted at Texas Tech and NMSU using 585 British x Continental steers (avg BW 728 lb; nine pens/treatment:Exp. 1). Digestion trials (Exp. 2) were conducted at TAES in Amarillo and Texas Tech using the same diets as Exp. 1. Dietary effects on potential ammonia losses were determined using feces and urine from the digestion trials in an *in vitro* (Exp. 3) and an *in vivo* (Exp. 4) system. A phase feeding trial was conducted at NMSU in which the CP concentration of the diets was decreased with 56 days left on feed (Exp. 5). The effects of oscillating dietary CP on performance and potential ammonia losses were determined in Exp 6. Ammonia emissions were measured using micrometeorology methods at a 50,000 head feedyard during 4 seasons in Exp. 7. In Exp. 1, CP concentration affected ADG ($P <$ 0.05) quadratically. Increasing the dietary concentration of supplemental urea relative to cottonseed meal linearly increased ADG and G:F ($P < 0.05$). Dry matter intake was not affected ($P > 0.10$) by either CP concentration or source. Fecal N excretion was not

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affected by CP concentration but urinary N excretion increased with increasing dietary CP concentration and with days on feed in Exp. 2. Potential ammonia emissions increased with increasing dietary urea (Exp. 3) and CP concentration (Exp. 3 & 4). Ammonia losses were approximately 25% greater in steers fed 13% CP diet than in steers fed 11.5% CP diets. Ammonia losses increased exponentially with days on feed (Exp. 3). Phase feeding decreased potential ammonia losses by approximately 25% but adversely affected animal performance (Exp. 5). Oscillating dietary CP (10 vs 14% at 48 hr intervals) tended to improve steer performance (Exp. 6) and decrease ammonia losses compared to continuously feeding a 12% CP diet. Ammonia emissions from a feedyard during the summer were 2x greater than in the winter and the annual average was 33 lb / head or approximately 50% of N intake (Exp. 7).

Introduction

Effects of livestock feeding operations on the environment is a growing concern among producers, regulators, and the public. Balancing rations so that animal performance and economics are balanced with potential environmental effects is a challenge for nutritionists. Much of the research used to determine protein requirements of finishing beef cattle is based on studies with dry-rolled corn based diets. Little data are available on the protein requirements of cattle fed diets based on steam-flaked corn. Galyean (1996) suggested, and Milton et al. (1997a, 1997b) confirmed that protein (especially degradable intake protein: **DIP**) requirements are affected by the degradability of diet concentrate.

In 2000, members of the Consortium for Cattle Feeding and Environmental Sciences (**CCFES**: comprised of USDA-ARS, Bushland, TX; TX Agric. Exp. Stat., Amarillo; Texas Tech Univ., Lubbock; West Texas A&M Univ., Canyon; New Mexico State Univ., Clayton Research Center, Clayton; Texas Cooperative Extension Serv., Amarillo; Texas A&M Veterinary Diagnostic Lab, Amarillo; and Texas Cattle Feeders Association, Amarillo) designed a series of research studies with the objectives to determine the effects of concentration and source of supplemental CP on feedlot performance, carcass characteristics, serum urea N concentrations, nutrient excretion, site and extent of digestion, and ammonia emissions of finishing beef steers fed steam-flaked corn-based diets and to evaluate relationships between nutrition, animal performance, and environmental variables. Treatments were designed to encompass values in the literature, as well as diets typically used in the industry (Galyean and Gleghorn, 2001).

Materials and Methods

The results of seven experiments will be reported. They include two performance trials (Exp. 1), two digestion trials (Exp. 2), two ammonia emission studies (Exp. 3 and 4), a phase feeding study (Exp. 5), an oscillating CP trial (Exp. 6), and a feedyard ammonia emission trial (Exp. 7).

Experiment 1 - Performance trials (Gleghron et a., 2004). Two performance trials were conducted; one at the Clayton Livestock Research Center and a second at the Texas

Tech Univ. Burnett Center. Steers were fed one of nine experimental diets (Table 1) that consisted of three formulated CP concentrations (11.5, 13.0, and 14.5% of DM) and three sources (% N basis) of supplemental CP (all urea = U; a 50:50 blend of urea and cottonseed meal = B; or all cottonseed meal = C) arranged factorially. With the exception of the protein fraction, all diets were formulated to meet the nutrient requirements for finishing beef steers gaining in excess of 1.6 kg/day (NRC, 2000).

At Clayton, 375 crossbred medium- to large-framed (British x Continental; average initial BW 785 ± 62 lb) steers were used (start date February, 2001) and at Texas Tech, 236 medium- to large-framed steers (British x Continental; average initial BW 671 ± 55 lb) were used (start date April, 2001). A total of 36 pens (10 steers/pen; 4 pens/treatment) with four weight blocks were used at Clayton and 45 pens (5 steers/pen and 5 pens /treatment) with five weight blocks were used at Texas Tech. Steers were initially implanted with Ralgro (Schering-Plough Anim. Health, Union, NJ) and were reimplanted with Revalor-S (Intervet; Millsboro, DE) on d 56 of the experiment. Cattle were slaughtered when average backfat thickness of the block was estimated by ultrasound to be 0.5 inches. Carcass data were collected by personnel from the Beef Carcass Research Center at West Texas A&M University, Canyon.

Feedlot performance and carcass characteristics from the two trials were pooled across location and analyzed using PROC MIXED (SAS Inst., Inc., Cary, NC). Pens were the experimental unit.

Table 1. Simplified composition (% DM basis) of diets fed in Experiments 1, 2, 3 and 4 (see Gleghorn et al., 2004 for details)

Diet CP & supplement	Corn	Alfalfa	Cottonseed meal	Urea	CP	DIP
11.5% - U	80.6	9.73	0	0.49	11.98	6.7
11.5% - B	79.3	9.73	1.67	0.26	11.98	6.4
11.5% - C	77.5	9.73	3.71	0	11.80	6.1
13.0% - U	79.8	9.73	0	1.02	13.10	8.2
13.0% - B	76.9	9.74	3.52	0.56	13.31	7.7
13.0% - C	73.3	9.75	7.78	0	13.41	7.0
14.5% - U	79.1	9.73	0	1.55	14.50	9.7
14.5% - B	74.6	9.74	5.35	0.85	14.70	8.9
14.5% - C	69.1	9.76	11.87	0	14.70	8.2

[a]U = 100% urea:0% CSM; B = 50% urea:50% CSM; C = 0% urea:100% CSM (% N basis).

Experiment 2 - Digestion studies (**Gueye, 2003; Gueye et al., 2003a, 2003b; McBride, 2003; McBride et al., 2003**). Fifty-four crossbred steers (average initial BW = 693 lb) were used in the study. Half of the steers were located at the USDA-ARS/TAES experimental feedlot at Bushland, TX and the other half were located at the Texas Tech University Research Center in New Deal, TX. All procedures were the same at both locations. Steers (six/treatment) were randomly assigned to one of the nine dietary treatments used in Exp. 1 (Table 1). Three nutrient balance trials were conducted; one at approximately 30 days on feed, one at approximately 75 days on feed, and one at approximately 120 days on feed. Feces and urine were collected, weighed, sampled, and composited for a 5-day collection period.

Experiment 3: In vitro ammonia study. Unacidified urine and fecal samples collected from steers in Exp. 2 were used to determine potential ammonia emission from feces and urine (Cole et al., 2005). Briefly, the in vitro ammonia emission system (Shi et al., 2001; Cole et al., 2005) was comprised of 48 sealed polyethylene chambers each attached to ammonia trapping bottles containing 0.9 M sulfuric acid and a vacuum system. To each chamber was added 1,550 g of screened soil followed by the feces and urine excretion of one steer (2 chambers/steer). The quantity of urine and feces added to each chamber was equal to 1% of the daily excretion by the steer during the nutrient balance trial. Ammonia losses were measured for 7 d at room temperature.

Experiment 4 - In vivo ammonia study (Todd et al., 2006). Eight steers (1,100 lb) were fed diets that contained either 11.5 or 13% CP (Table 1: all urea supplements). For seven days steers were tethered in tie stalls and all urine and feces from each steer were collected, weighed, and frozen. For the *in vivo* field study, two circles (one for the 11.5% CP diet manure and one for the 13% CP diet manure) with 16–ft radius were excavated to a depth of 7 inches. The 860 ft^2 of each circle was approximately equivalent to the pen area typically allotted to five cattle in southern High Plains feedyards. Fresh pen surface scrapings from a local commercial feedyard were then packed in the excavated circles to create an artificial pen surface and an 8 ft tall mast was erected in the center of each circle. On each mast, gas washing bottles were installed at heights of 6, 10, 16, 24, 48 and 96 inches to trap ammonia. Profiles of wind speed and air temperature were also determined at the same heights as atmospheric ammonia concentration using cup anemometers and aspirated, fine-wire thermocouples, respectively. Ammonia flux was estimated using the Integrated Horizontal Flux (**IHF**) method (Wilson and Shum, 1992). Four trials, one each in summer, autumn, winter, and spring were completed, each lasting 29 days. For each trial, thawed urine and feces (equivalent to daily excretion of 5 steers) were uniformly applied over the circles and ammonia concentration profiles were measured on days 1, 2, 4, 7, 11, 16, 22, and 29 after applications.

Experiment 5 - Phase feeding study (Gleghorn et al., 2005; Cole et al., 2006). Three-hundred eighteen crossbred medium- to large-framed (British x Continental; initial BW 693 ± 11 lb) beef steers were used at the Clayton Research Center. Steers were randomized to 36 pens (six weight blocks and six dietary treatments: 8 to10 steers/pen). The six treatments consisted of the following: 1) 11.5% CP diet fed throughout the study (**11.5)**; 2) 13.0% CP diet fed throughout the study (**13.0%**); 3) initially fed an 11.5% CP diet and switched to a 10% CP diet with approximately 56 d left on feed (**11>10**); 4) initially fed a 13.0% CP diet and switched to an 11.5% CP diet with approximately 56 d left on feed (**13>11);** 5) initially fed a 13.0% CP diet and switched to a 10% CP diet with approximately 56 d left on feed (**13>10);** and 6) initially fed an 13.0% CP diet and switched to an 11.5% CP diet with approximately 28 d left on feed (**13>>11).** Compositions of the diets are presented in Table 2. All steers received an initial Component-ES implant (Vetlife, Overland Park, KS) and were reimplanted with Revalor-S (Intervet; Millsboro, DE) on d 56 of the experiment. Blocks of steers were slaughtered when approximately 60% of the steers within the block had a visually estimated 12th rib fat thickness of 0.4 inches.

To estimate N volatilization losses, samples of air-dry manure were collected from the concrete feed bunk pads in each pen the day before diets were changed and again the day after cattle were slaughtered. Apparent N volatilization losses were estimated based on the change in the N:P ratios of diets and the air-dried pen manure.

Experiment 6 - Oscillating crude protein (Cole et al., 2003). In Performance Trial 6A ninety-two crossbred steers (average BW = 898 $\pm$ 6 lb) were randomly assigned to one of 12 pens and three treatments (4 pens/treatment) at the USDA-ARS/TAES Research Feedlot in Bushland, TX. Steers were continuously fed a finishing diet with 14% CP, were continuously fed a 12% CP diet, or were fed oscillating concentrations of CP (10 or 14% CP) at 2-d intervals (Table 3). Steers were initially implanted with Synovex-S (Fort Dodge Animal Health, Overland Park, KS) and reimplanted at 56 d on feed with Revalor-S (Intervet, Millsboro, DE.). Individual steers were selected from pens for harvest when their projected 12th -rib fat thickness, based on ultrasound measurements, was 0.4 in.

Table 2. Ingredient and chemical composition of diets fed in Experiment 5

Ingredient or chemical component	Dietary CP concentration, % of DM		
	10	11.5	13.0
Steam-flaked corn	80.00	79.45	76.35
Alfalfa hay	10.50	10.50	10.50
Cottonseed meal	0	0	2.75
Urea	0	0.55	0.90
Molasses +fat	7.00	7.00	7.00
Supplement	2.50	2.50	2.50
Chemical component[a]			
CP, %	9.59	11.11	13.08
DIP, % DM	4.95	6.53	8.15

[a] Crude protein is analyzed value, DIP was calculated from NRC (2000).

In an individual feeding study (Experiment 6B), 27 steers (average BW = 891 $\pm$ 10 lb) were trained to eat from individual feeders, weighed, implanted with Synovex-S, and randomly assigned to three pens with 9 steers/pen. Within each pen, three steers were randomly assigned to each of the three dietary regimens used in Exp. 6A (Table 3). Arterial blood, venus blood, and fresh fecal samples were obtained each morning of d 14 through 17 and 42 through 45.

Table 3. Composition of diets (% DM basis) fed in Experiment 6[a]

Item	10 %	12%	14%
Corn, steam flaked	80.0	80.0	80.0
Sudan hay	5.0	5.0	5.0
Cottonseed hulls	5.0	5.0	5.0
Supplement	10.0	10.0	10.0
Chemical component			
CP, %	10.0	12.1	14.1
DIP, %	4.4	6.3	8.1
NEg, Mcal/kg	1.39	1.38	1.37

[a] Diets containing 12% CP were a 50:50 blend of 10% CP and 14% CP diets.

Experiment 7 – Feedlot ammonia emissions (Todd et al., 2005). Experiment 7 was conducted at a 50,000-head commercial feedyard located in the Texas Panhandle. Occupancy ranged from 42,000 to 49,000 head during the trials. Stocking density was about 150 ft^2 $head^{-1}$ in summer and about 180 ft^2 $head^{-1}$ in winter. Five field campaigns were conducted; during summer 2002, 2003, and 2004, and during winter 2003 and 2004. During each campaign, a 20- to 33-foot instrument tower was installed in an unoccupied pen. Ammonia concentrations were measured at 5 to 6 heights using gas washing. Profiles of wind speed and air temperature were determined at the same heights as atmospheric ammonia concentration. Ammonia flux was estimated using the flux gradient method. Diet and pen manure samples were collected and analyzed for N and P content. Total gaseous N volatilized from feedyard pens was estimated by the change in N:P ratio of ration and dried manure.

Results and Discussion

Experiment 1 – Performance trials. Pooled performance data are presented in Table 4. No interaction was detected ($P > 0.10$) between CP concentration and CP source. During the first 56 d, average daily gain (**ADG**) increased linearly ($P = 0.03$) with increasing CP concentration but for the overall feeding period, CP concentration quadratically affected ADG ($P = 0.02$). The maximum ADG for the entire feeding period occurred with a CP concentration of 13%. No significant differences in ADG were observed among CP sources for the overall feeding period (Table 4). However, for the interim periods and the overall trial, ADG was numerically greatest for cattle receiving all supplemental protein in the form of urea, intermediate for the blend of urea and cottonseed meal, and least for all cottonseed meal.

Neither CP concentration nor CP source affected dry matter intake (**DMI**) for the overall feeding period (Table 4); however, during the first 56 and 112 days on feed, DMI increased linearly with increasing CP concentration ($P < 0.06$). Gain efficiency was not affected by CP concentration for the overall feeding period (Table 4); however, during the first 28 d on feed, G:F increased linearly (*P* = 0.01) with increasing CP concentration. Moreover, increasing the supplemental CP supplied by urea linearly increased G:F (*P* = 0.03) for the overall feeding period, with the greatest efficiency observed with all urea supplements.

These results suggest that effects of CP source on performance were somewhat less pronounced than effects of CP concentration. It is noteworthy, however, that G:F was consistently greatest for cattle receiving all supplemental CP from urea. This tends to contrast with results of protein supplementation studies using dry-rolled corn-based diets (Milton et al., 1997b). These differences in results are probably attributable to differences in corn processing methods (i.e. ruminal digestibility). In the present study DIP (% of DM) ranged from 6.07 (treatment 11.5C) to 9.7% (treatment 14.5U). Peak performance was obtained with 13% CP- 100% urea diet which had a DIP concentration of 8.2% of DM; a value that is in close agreement with the optimal value of 8.3% proposed by Cooper et al. (2002) for steam-flaked corn-based diets. Based on calculations using the NRC (2000) metabolizable protein (**MP**) system, the CP requirement of steers in this trial, assuming the diet could be perfectly balanced for DIP (8.49% of DM) and UIP (4.13% of DM) would be 1,159 g/d, or 12.62% of the diet. Among the nine experimental diets the 13%, all-urea diet (8.2% DIP and 4.8% UIP) provided the best match to the NRC (2000) recommendations. This diet is similar to values routinely used in commercial feedyards (Galyean and Gleghorn, 2001) and tends to agree with CP requirements reported by Thomson et al. (1995) in steers fed steam-flaked sorghum-based finishing diets. However, Biggs et al (2004) suggested that 11.5% CP was adequate for cattle fed steam-flaked corn diets.

Hot carcass weight (**HCW**) responded quadratically (*P* = 0.02) to increasing CP concentration, with heaviest HCW observed with 13% CP; this result reflected the differences in ADG (Table 4). Increasing supplemental CP from urea linearly increased (*P* = 0.02) HCW. Although absolute differences were small, USDA Yield Grade tended (*P* = 0.07) to increase with increasing CP concentration. Longissimus muscle area and dressing percentage increased linearly (*P* < 0.05) as concentration of supplemental CP supplied by urea increased. Marbling score, percentage of carcasses grading Choice and 12^{th} –rib fat thickness were not affected by CP concentration or source.

The effects of CP concentration on serum urea N (**SUN**) through day 112 are presented in Figure 1. In general, SUN concentrations increased with increasing dietary CP concentration but were not affected by CP source. Serum urea nitrogen concentrations increased as days on feed increased except on day 84. This is probably attributable to reimplanting the cattle on d 56 and subsequent increase in N retention.

Previous research suggests that SUN concentrations greater than approximately 8 mg/dL are indicative of excessive N intake and N wastage (Johnson and Preston, 1995; Cole et al., 2003). At all collection periods, SUN concentrations for cattle fed the 11.5% diet were near or below the 8 mg/dL threshold suggesting that this concentration of CP might be near or below the minimum required concentration.

Table 4. Effects of crude protein concentration and source on performance and carcass characteristics in Exp. 1[a]

Item and period	% Crude protein			Supplemental CP source			SEM
	11.5	13.0	14.5	Urea	Blend	CSM	
ADG, lb							
d 0-56	4.09	4.40	4.42	4.36	4.31	4.25	0.15
d 0 to end	3.63	3.76	3.67	3.72	3.67	3.65	0.28
DMI, lb							
d 0 to 56	18.33	19.10	19.14	19.00	18.96	18.63	0.61
d 0 to end	19.95	20.46	20.17	20.15	20.26	20.17	1.86
Gain:feed, g/kg							
d 0 to 56	225	230	232	230	229	228	4
d 0 to end	182	184	183	185	183	182	3
HCW, lb	812	827	821	827	821	814	14.6
Choice, %	55.2	54.7	49.0	53.4	57.7	47.7	--
Yield grade	2.74	2.82	2.95	2.88	2.82	2.81	0.20

[a]U = 100% urea:0% CSM; B = 50% urea:50% CSM; C = 0% urea:100% CSM (% N basis).

Table 5. Effect of crude protein concentration on N metabolism at approximately 30, 75 and 120 days on feed in Experiment 2.

Day of sampling and item	CP concentration, %			SEM
	11.5	13.0	14.5	
Day 30 on feed				
N intake, g/d	118*	132	142	5.5
N Digestion, %	69.5	69.3	67.9	2.0
N retained, g/d	42.9*	31.1	25.0	7.0
N retained, %	35.4*	23.2	17.7	5.1
Day 75 on feed				
N Intake, g/d	110*	125	138	6.9
N Digestion, %	59.3*	63.7	65.4	2.0
N retained, g/d	21.9	18.8	17.8	5.2
N retained, %	26.1	21.9	19.2	7.4
Day 120 on feed				
N Intake, g/d	104*	125	129	10.7
N Digestion, %	56.5*	63.6	63.2	2.8
N retained, g/d	-2.9	-6.5	-8.2	9.1
N retained, %	-8.5	-7.0	-7.1	7.1

* Linear effect, $P < 0.05$ or greater.

Figure 1. Effect of crude protein concentration on serum urea N concentrations across time for pooled data from Exp. 1. [a,b]Means within a time period that do not have a common superscript differ ($P < 0.05$).

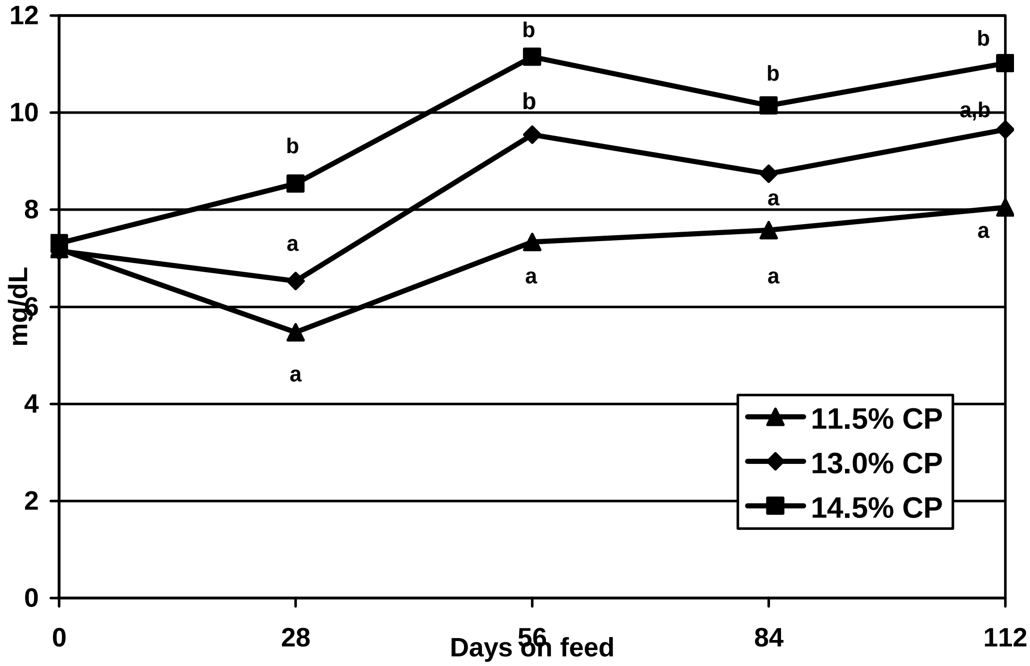


Table 6. Effect of days on feed on N and P balance of steers fed diets containing 11.5,13 or 14.5% CP in Experiment 2.

Item	Approximate days on feed < 30	75	> 120	SEM
N Intake, g/d	130	125	119	4.1
N Digestion, %	68.7	62.8	61.0	1.2
Urine N, g/d	57.4	59.8	81.8	2.2
N retained, g/d	32.4	19.5	-7.5	3.2
N retained, %	24.7	14.6	-8.8	2.7
P intake, g/d	19.4	17.7	16.3	0.93
P digestion, %	50.9	37.4	34.1	3.8
P retained, g/d	8.6	4.8	2.2	0.95
P retained, %	41.2	25.9	12.2	3.49

Experiment 2 - Digestion studies. Nitrogen intake increased (Linear effect, $P < 0.05$) with dietary CP concentration (Table 5). As dietary CP concentration increased, the quantity of urinary N excreted increased (Linear effect; $P < 0.01$; data not shown). On days 75 and 120, N digestion decreased as CP concentration decreased (Linear effect; $P < 0.03$). Nitrogen retention was not significantly affected by diet.

Nitrogen intake, N digestion, urinary N excretion, N retention, P intake, P digestion, and P retention were significantly affected by days on feed (Linear effect; $P < 0.03$; Table 6)

Experiment 3 - In vitro ammonia study (Cole et al., 2005). Cumulative ammonia-N losses were greater ($P < 0.05$) for the 13% CP diet than the 11.5% CP diet, with the 14.5% CP diet being intermediate (Table 7). The quantity of ammonia lost over the 7-day incubation period, ammonia losses as a percentage of urinary N applied, and total N losses were greater ($P < 0.05$) from calves fed the 13 and 14.5% CP diets than calves fed the 11.5% CP diet (Table 7). However, total N lost as a percentage of urinary N applied was greater ($P < 0.05$) for the 11.5% CP diet than the 13 and 14.5% CP diets. The somewhat lower ammonia emissions from urine+feces of steers fed the 14.5% CP diet than from steers fed the 13% CP diet was somewhat unexpected; however, the lack of large differences in ammonia losses between the 13% and 14.5% diets could be due to the small differences in N intake and (or) in other constituents in the urine such as hippuric acid (Whitehead et al., 1989). On average, ammonia-N accounted for 43.1 $\pm$ 2.17% of the total N loss. Thus, approximately 57% of N losses must have occurred as dinitrogen gases, amines, or other N-containing gases. Cumulative 7-day ammonia-N losses increased ($P < 0.05$) with increasing dietary urea concentration (Table 7).

Table 7. Cumulative ammonia N emitted and total N losses over 7-d from in vitro chambers in Experiment 3 (overall LS means of days 30, 75, and 120).

Item	Dietary CP, % DM			Urea:cottonseed meal			SEM
	11.5	13.0	14.5	0:100[a]	50:50	100:0	
NH_3-N lost, mg	17.55[b]	35.09[c]	29.41[d]	23.99[b]	26.38[c]	31.67[d]	1.45
Total N lost, mg	136.7[b]	178.4[c]	165.8[c]	167.0	147.8	166.0	10.4
NH_3-N, % urine N	3.2[b]	4.3[c]	4.3[c]	3.9	3.8	4.1	0.11
N lost, % urine N	37.3[b]	25.9[c]	27.0[c]	33.1	26.1	31.1	2.14
NH_3-N, % N lost	44.6	43.1	42.0	42.0	45.4	42.2	2.17

[a] Urea:cottonseed meal ratio in supplement (N basis).
[bcd] Means in same row and main treatment comparison without a common superscript letter differ ($P < 0.05$).

Cumulative ammonia-N losses and the proportion of urinary N lost as ammonia-N increased as days on feed increased (Table 8; $P < 0.05$). This was due in part to greater urinary N applications as days on feed increased. The high (12.4 mg/100 mL) blood urea N concentrations of steers during the sampling period at 120 days on feed indicated the cattle had reached their appropriate harvest weight, that their protein requirements were lower than during the earlier sampling dates, and that protein was probably being fed in excess of requirements. In fact, N retentions were low to negative during the day 120 sampling period (Gueye et al., 2003a; McBride et al., 2003). As steers approach their market or mature weight, protein deposition decreases (NRC, 2000). Thus, if protein intake remains the same as animals increase in body weight, as it did in this study, the proportion and quantity of dietary N excreted in the urine and the proportion of urinary N that is urea-N increase. This potentially leads to increased ammonia emissions later in the feeding period.

For the three sampling periods, ammonia-N emissions were highly correlated to urinary N applied ($r^2 = 0.69$; $P < 0.001$) but not to fecal N applied, total N intake, DIP-N intake, or DMI. Obviously, the quantity of urinary N excreted has a major effect on ammonia emissions and urinary N is the primary source of ammonia emission from the pen surface (Mason, 2004; Cole et al., unpublished data). With dairy cows Kebreab et al. (2004) reported a strong exponential relationship between N intake ($r^2 = 0.67$) and urinary N excretion with a point of inflection of approximately 400 g N intake/d (14.7% CP). They suggested that at a daily N intake of approximately 400 g, N was excreted equally in the feces and urine but that above 400 g/d most the extra N was excreted in the urine. Although such a range was not tested in the present study, a similar excretion pattern would be expected in beef cattle.

These results demonstrate that potential daily ammonia emissions from beef cattle manure can be affected by the CP and urea concentration of the diet. However, effects on animal performance under practical conditions must also be considered. Based on results of the complete N balance trial (Exp. 2; Gueye et al.,2003a; McBride et al., 2003), and two performance trials (Exp. 1; Gleghorn et al., 2004) using the same diets as used in this trial, the actual CP requirement for optimal performance and maximal N retention was between 11.5 and 13% CP.

Table 8. Cumulative ammonia-N, and N losses in Experiment 3 (overall LS means).

Item	Collection period (days on feed)			SEM
	< 30[a]	75	>120	
NH_3-N lost, mg	13.26[b]	26.66[c]	41.04[d]	1.19
N lost, % added N	15.3	13.2	15.6	0.88
NH_3-N lost, % urine N	2.8[b]	3.8[c]	5.6[d]	0.11
N lost, % urine N	37.6	25.0	27.7	2.14
NH_3-N lost, % N lost	38.1[b]	46.3[c]	45.0[c]	2.17

[a] Approximate days on feed when feces and urine were collected.
[b,c,d] Means in same row without a common superscript letter differ ($P < 0.05$).

Experiment 4 - In vivo ammonia study (Todd et al., 2006). Nitrogen in collected urine comprised 66.2% of total N excretion in the 11.5% treatment compared with 72.7% in the 13% treatment. Total fecal + urine N applied to the artificial pen circles averaged 534 g for the 11.5% treatment and 570 g for the 13% treatment. The difference was primarily due to greater urinary N in the 13.0% CP treatment. Ammonia volatilized rapidly during the first two days: most likely due to rapid hydrolysis of urea in urine.

Decreasing CP in the diet from 13.0% to 11.5% significantly ($P < 0.10$) decreased ammonia flux density in summer (36%), autumn (44%) and spring (26%), but not in the winter (Figure 2). Assuming these reductions were typical of the seasons, decreasing CP in steer diets from 13.0% to 11.5% reduced mean daily ammonia flux by 28% on an annual basis.

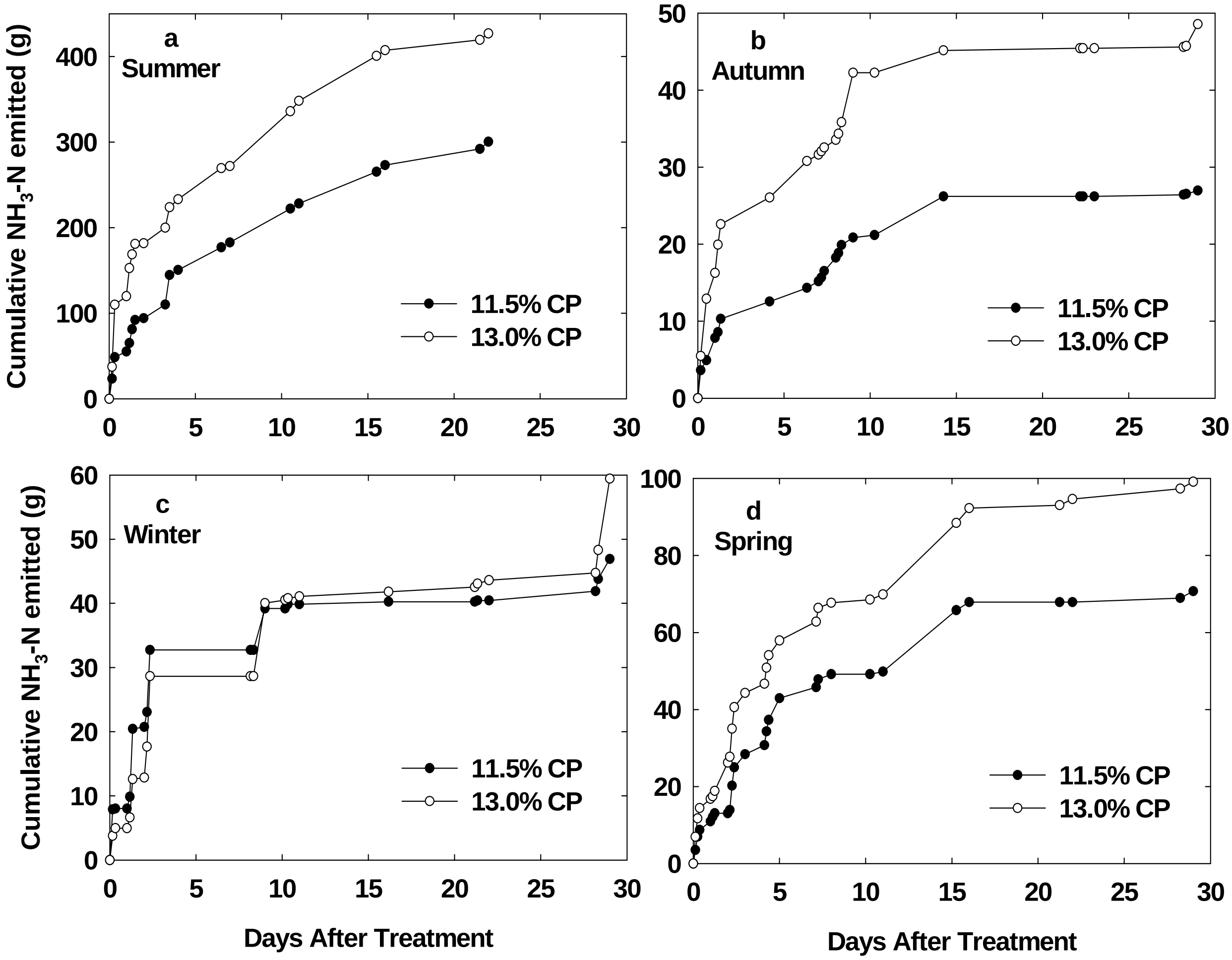


Figure 2. Cumulative measured NH_3-N emitted; summer trial began on 22 July 002; autumn trial began on 212 October 2002; winter trial began on 10 February 2003; and spring trial began on 14 April 2003.

Mean daily ammonia flux was greatest during the summer trial (12.9 µg m^{-2} s^{-1}). Summer fluxes generally decreased with time after treatment, though increased flux was sometimes observed following precipitation. Mean daily flux rates in autumn, winter and spring did not exceed 4 µg m^{-2} s^{-1}. Greatest losses during summer are explained by much warmer temperatures than in other seasons, which enhanced NH_3 volatilization. Though winter temperatures were coldest, NH_3-N losses were least in autumn because greater precipitation during that season suppressed ammonia volatilization.

Integration of the area beneath the emission curve for the summer trial gave estimates of total NH_3-N loss of 394 g and 582 g (79.1% and 99.5% of the applied N) for the 11.5% and 13% treatments, respectively, so that decreasing CP from 13% to 11.5% reduced total NH_3-N loss by 32%.

Experiment 5 - Phase feeding study. During the first 56 d on feed, steers fed the 13% CP diet had greater ($P < 0.10$) ADG and DMI ($P < 0.05$) than steers fed the 11.5% CP diet; however, G:F was not affected by CP concentration (Table 9). During the first 112 d on feed, steers fed the 13% CP diet had greater ($P < 0.05$) DMI than steers fed the 11.5% CP diet; however, ADG and G:F were not affected by CP concentration (Table 9). These results agree with those of Exp. 1 (Gleghorn et al., 2004).

Table 9. Effects of dietary crude protein concentration on cattle performance and N volatilization during the first 56 and 112 d of the feeding period in Experiment 5

Item	Dietary CP, % DM		SEM
	11.5	13.0	
Initial shrunk BW, kg	303	302	4.58
d 0 to 56			
ADG, lb	3.10[†]	3.26	0.044
DMI, lb	15.0*	15.9	0..26
G:F, lb/lb	0.207	0.208	0.029
d 0 to 112			
ADG, lb	3.30	3.39	0.033
DMI, lb	16.1*	16.6	0.22
G:F, lb/lb	0.206	0.205	0.028
N volatilization d 0 to 112			
% of N intake	55.9[*]	59.1	0.97
lb / steer	18.02[*]	23.19	0.70

[*] Treatments differ, $P < 0.05$.
[†] Treatments differ, $P < 0.10$.

Average daily gain, DMI, and G:F during the last 56 d on feed increased ($P < 0.05$) with increasing dietary CP concentration (data not shown). Steers continuously fed the 11.5% CP diet had performance that did not differ from that of cattle continuously fed the 13.0% CP diet; however, steers switched from the 13.0% CP diet to the 11.5% CP diet had lower ($P < 0.05$) ADG than those continuously fed the 11.5 and 13% CP diets, lower ($P < 0.05$) DMI than steers continuously fed the 13% CP diet, and a numerically lower G:F than steers continuously fed the 11.5 and 13% CP diets. Switching steers from the 13.0% CP to 10% CP diet had a dramatic ($P < 0.05$) adverse effect on ADG, DMI, and G:F. Switching from 13.0 to 11.5% CP during the last 28 d on feed seemed to have a greater effect on performance than switching diets with 56 d left on feed suggesting there is an adaptation period when the dietary CP concentration of the diet is changed.

Animal performance data for the entire feeding period are presented in Table 10. Overall, performance by cattle continuously fed the 11.5 and 13.0% CP diets was not significantly different; however, cattle continuously fed the 11.5% CP diet had numerically lower ADG (2.8%) and DMI (4.2%) than steers continuously fed the 13.0% CP diet. Average daily gains and DMI in this trial were considerably less than values in Exp. 1 (Gleghorn et al., 2004) in cattle fed similar diets. Nonetheless, Gleghorn et al.

(2004) also noted a numerically greater performance by steers fed 13% CP diets compared with 11.5% CP diets. Decreasing the dietary CP from 13.0 to 11.5% or from 11.5% to 10% with 56 d left on feed did not significantly affect overall ADG, DMI, or G:F (Table 10). Decreasing the dietary CP concentration from 13.0 to 10% with 56 d left on feed or from 13.0 to 11.5% with 28 d left on feed decreased ($P < 0.05$) ADG and DMI. Gain:feed of steers continuously fed the 11.5% CP diet was greater ($P < 0.05$) and gain:feed of steers continuously fed the 13% CP diet tended ($P < 0.10$) to be greater than steers in which the dietary CP concentration was decreased from 13.0 to 10% with 56 d left on feed. These results tend to contrast with several studies that reported phase feeding did not significantly affect performance by cattle fed dry-rolled corn-based diets (Erickson, et al., 1999; Cooper et al., 2000; Trenkle, 2002) or steam-flaked corn-based diets (Vasconcelos et al., 2004a, 2004b, 2006). Differences in results between previous research and the present study may be attributable in part to differences in corn processing methods (i.e., different DIP requirements) and implanting strategies. The calculated DIP values for the experimental diets in the present trial based on NRC (2000) values were 5.08, 6.63, and 8.21% of DM for the 10, 11.5, and 13.0% CP diets, respectively. Thus, the calculated DIP concentrations of the 10 and 11.5% CP diets were below estimated DIP requirements (Cooper et al., 2002; Gleghorn et al., 2004).

Cattle continuously fed the 13.0% CP diet had heavier ($P < 0.05$) HCW (812 lb) than steers switched from 13.0% to 10% (772 lb) or switched from 13.0% to 11.5% with 28 d left on feed (781 lb). The HCW of the remaining treatments were not affected by diet (overall mean = 790 $\pm$ 6 lb). Dietary treatment did not significantly affect yield grade (2.9 $\pm$ 0.05), LM area (13.7 $\pm$ 0.13 in^2), 12th rib fat thickness (1.39 $\pm$ 0.03 cm), marbling score (Small^{42} $\pm$ 7.3), and dressing percentage (61.8 $\pm$ 0.15%). A greater ($P <$ 0.05) percentage of steers continuously fed the 13.0% CP diet graded Choice than steers switched from 13.0% to 11.5% with 28 d left on feed (72 vs. 50%). There were no significant differences in percentage of Choice carcasses for the remaining treatments (overall mean = 65.3 $\pm$ 3.2%).

Estimated N volatilization losses during the first 112 d (Table 9) and last 56 d (Table 11) were significantly affected by dietary CP concentration. As a percentage of N intake and as g/d, N volatilization losses of steers continuously fed the 11.5% and 13% CP diets were greater during the last 56 d on feed than during the first 112 d on feed. This finding agrees with our previous results (Exp. 3; Cole et al., 2005) and suggests that N volatilization losses, as a percentage of N intake, increase with days on feed, most likely as a result of greater urinary N excretion. Nitrogen volatilization losses over the entire feeding period (Table 11) were affected by dietary CP regimen. Phase feeding decreased N volatilization losses by 7 to 11 lb/steer (approximately 20 to 25%). Similarly, feeding the 11.5% CP diet throughout the feeding period decreased N volatilization losses by approximately 9.7 lb/steer, or 22% compared with continuous feeding of the 13.0% CP diet. These decreases in estimated N volatilization losses are similar to previous reports (Erickson et al., 1999; Cole et al., 2005; Todd et al., 2006). Erickson et al. (1999) reported a significant 14.7 lb decrease in N volatilization losses of yearlings phase-fed during the summer and a non-significant 4.4 lb decrease in N volatilization losses of calves phase-fed during the spring and winter. In their study, N volatilization losses were similar to values from our trials: 58% of N intake in the summer and 35% in the winter.

Table 10. Effects of phase feeding of dietary crude protein on cattle performance during the entire feeding period in Experiment 5

Treatment [a]	ADG, lb	DMI, lb	G:F, lb/lb
11.5	3.12	16.81	0.186
13.0	3.21	17.51	0.184
11.5>10	3.06	16.52[b]	0.185
13.0>11.5	3.12	16.83	0.186
13.0>10	2.97[b]	16.63[b]	0.178[cd]
13.0>>11.5	2.99[b]	16.65[b]	0.181
SEM	0.031	0.19	0.017

[a] See text for treatment descriptions.
[b] Mean differs from continuous 13.0% CP diet, $P < 0.05$.
[c] Mean differs from continuous 11.5% CP diet, $P < 0.05$.
[d] Mean tends to differ from continuous 13.0% CP diet, $P < 0.10$.

Table 11. Effects of phase feeding of dietary crude protein on apparent N volatilization losses over entire the feeding period in Experiment 5

Treatment[a]	% of N intake	g/steer daily	lb/steer
11.5	61.5	83.7[b]	33.40[b]
13.0	64.6	107.6[c]	43.05[c]
11.5>10	51.2[bc]	65.6[bc]	26.18[bc]
13.0>11.5	58.7[b]	89.7[b]	35.86[b]
13.0>10	55.2[bc]	80.2[b]	32.05[b]
13.0>>11.5	57.3[b]	88.0[b]	35.00[b]
SEM	1.08	2.83	1.03

[a]See text for treatment descriptions
[b]Mean differs from continuous 13.0% CP diet, $P < 0.05$.
[c]Mean differs from continuous 11.5% CP diet, $P < 0.05$.

Experiment 6 - Oscillating crude protein. In Exp. 6A, steers fed the 14% CP diet had greater ($P = 0.04$) ADG, and tended ($P = 0.09$) to have greater gain:feed than steers fed the 12% CP diet (Table 12). Steers fed the oscillating CP regimen had intermediate performance.

Table 12. Performance of steers fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets in Experiment 6A

Item	12% CP	Oscillating	14% CP	SEM
Initial weight, lb	889	904	902	0.62
Average days on feed	115[a]	116[a]	105[b]	2.70
ADG, lb				
Day 56	5.41	5.39	5.61	0..08
Final	3.61[c]	3.81[cd]	4.14[d]	0.09
DMI, lb/d				
Day 56	26.2[c]	26.2[c]	28.4[d]	0.62
Final	25.3	25.5	27.5	0.64
Gain:feed ratio, lb/lb				
Day 56	0.208	0.205	0.199	0.034
Final	0.144[a]	0.150[ab]	0.152[b]	0.020

[ab] Means in same row without a common superscript letter tend to differ (P < 0.10).

[cd] Means in same row without a common superscript letter differ (P < 0.05).

Steers fed the 14% CP diet in Exp. 6B had greater ADG (P = 0.08) and gain:feed (P = 0.04) than steers fed the 12% CP diet, with steers fed the oscillating CP regimen being intermediate (Table 13). Steers fed the 14% CP diet tended to have greater predicted protein retention (P = 0.03), and urinary N excretion (P = 0.04) than steers fed the 12% CP diet (Table 13). Steers fed the oscillating CP regimen tended (P = 0.09) to have greater predicted protein retention than steers fed the 12% CP diet. Calculated average urinary N excretion was not significantly affected by oscillating CP (compared to a constant 12% CP diet).

Steers fed the oscillating CP regimen tended to have greater (P = 0.08) arterial bicarbonate, total carbon dioxide, blood base excess, and extracelluar fluid base excess than steers fed the 14% CP diet, with steers fed the 12% CP diet being intermediate. Many consultants feel systemic ammonia provided by higher protein diets may serve to buffer the high acid loads which occur with high concentrate diets. Based on this premise, feeding lower CP (or DIP) diets or oscillating between a relatively high and low CP (or DIP) diet could potentially cause additional problems with acidosis. However, in Trial 6B, the concentrations of all acid-base constituents measured were well within normal ranges for cattle; thus, suggesting that systemic buffering capacity was not altered by dietary regimen under the conditions of this study.

Results of oscillating CP feeding studies have been somewhat variable. This variability in results could be caused by several factors including timing of CP oscillations, CP concentrations in diets vs. animal requirements, degradability of CP, or diet composition/fermentability. However, Archibeque et al. (2004; 2006a) reported that daily fecal N excretion did not differ between steers fed 14% or 12% CP diets, but was reduced ($P < 0.05$) when steers were fed the oscillating CP diets. Nitrogen retention (g/d) was greater in steers and wethers fed the oscillating regimen compared to steers and wethers continuously fed a 12% CP diet (Archibeque et al., 2005; 2006b).

Table 13. Performance and calculated N balance of steers individually fed oscillating dietary CP concentrations or constant 12 or 14% CP diets for 56 days in Experiment 6B

Item	12% CP	Oscillating	14% CP	SEM
ADG, lb	3.61[a]	4.20[ab]	4.44[b]	0.16
DMI, lb	22.7	23.3	23.5	0.46
Gain:feed, lb/lb	0.158[c]	0.179[cd]	0.189[d]	0.051
N intake, g/d	197.7[c]	202.9[c]	239.8[d]	5.61
Protein retained[e], g/d	139.5 [c]	156.2[cd]	165.7[d]	4.23
N digested[f], % intake	85.4	86.2	86.9	1.06
Urine N[g], g/d	146.8[c]	149.9[c]	181.8[d]	4.99

[ab] Means in same row without a common superscript letter tend to differ ($P < 0.10$).

[cd] Means in same row without a common superscript letter differ ($P < 0.05$).

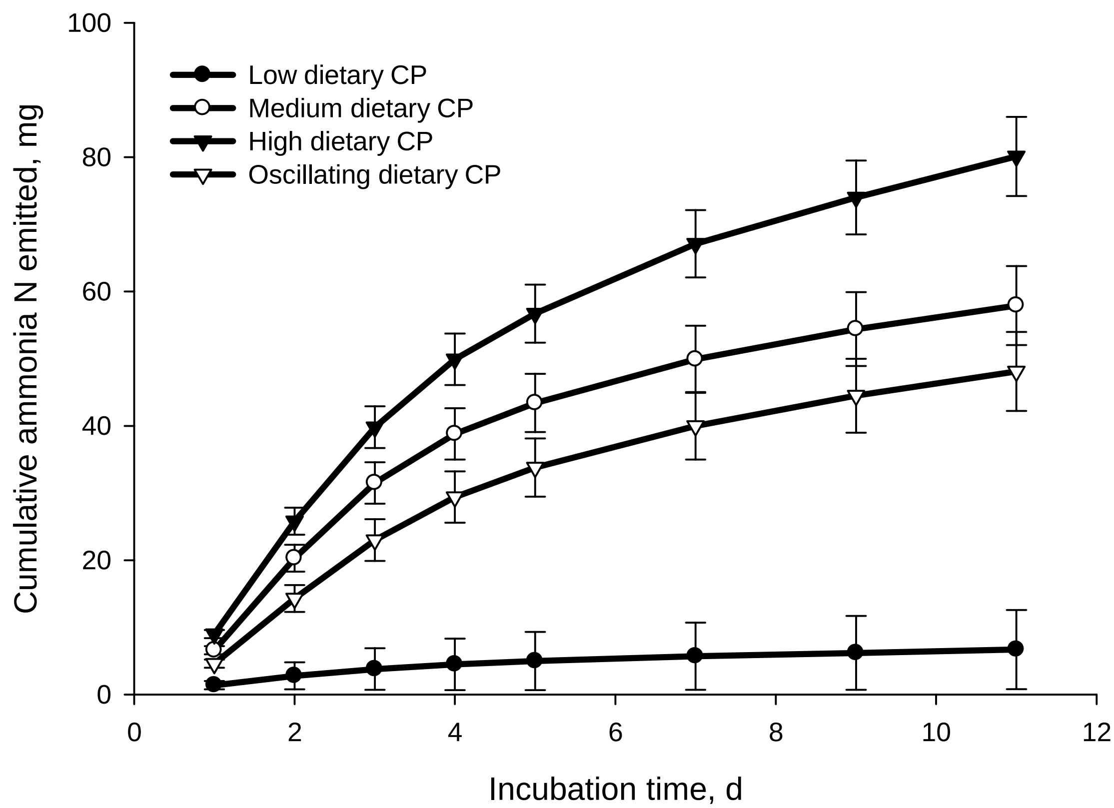
[e] Calculate as shrunk body gain x (268 - (29.4 x retained energy/shrunk body gain)); (NRC, 2000).

[f] Calculated using acid insoluble ash as an internal marker.

[g] Calculated as N intake - (fecal N + retained N).

Using the in vitro ammonia system described in Exp. 3, Archibeque et al. (2006a) noted an increase in the amount of ammonia released as dietary CP increased from the 10 to the 12 to the 14% CP diets (Figure 3). Ammonia emissions from the oscillating treatment were numerically lower than that of the 12% CP treatment. These data support previous findings that oscillating dietary CP may improve N retention of ruminants fed finishing diets compared to those fed similar quantities of CP in a static fashion. Additionally, the results of Archibeque et al. (2006a) demonstrate that the changes in manure composition of steers fed oscillating CP diets may be great enough to alter overall ammonia volatilization from these manures. This type of technique may provide a viable option for producers who are compelled to reduced ammonia emissions from feedlot operation without sacrificing performance.

Figure 3. Cumulative in vitro emission of ammonia N from manure of steers fed diets with 10%, 12%, 14%, or Oscillating dietary crude protein (Archibique et al., 2006a). Error bars indicate standard errors of the least square means.



Experiment 7 - Feedlot ammonia emissions. Atmospheric ammonia concentrations at the feedyard followed a typical diel course. Concentration increased from early morning and reached a daytime maximum near midday, then decreased into the early evening. Concentrations at a height of 6.5 ft averaged from 600 to 1,200 $\mu g\ m^{-3}$. Maximum concentrations which sometimes exceeded 3,000 $\mu g\ m^{-3}$ were measured at night during strongly stable conditions.

Mean daily NH_3 -flux density was highly variable from campaign to campaign. Summer flux ranged from 55 to 93 $\mu g\ m^{-2}\ s^{-1}$, averaging 70 $\mu g\ m^{-2}\ s^{-1}$. In agreement with Exp. 4, greatest variability in ammonia flux was related to frequent precipitation during the campaign: flux was suppressed immediately following precipitation then increased as feedyard pens dried. Greatest flux was observed when environmental conditions were hot and dry. Ammonia flux during the winter was half that of summer, averaging 34 $\mu g\ m^{-2}\ s^{-1}$. Ammonia-N loss in this study averaged 10,230 lb d^{-1} during summer and 4,708 lb d^{-1} during winter. This amounted to 55% of fed N during summer and 27% of fed N during winter. In an independent study coincident with this study at the same feedyard using open path lasers to measure ammonia concentration and a backward Lagrangian stochastic (bLS) model to estimate flux, Harper et al. (2004) noted ammonia emissions that were 53% of fed N in summer and 29% of fed N in winter. Based on the decrease in the N:P ratio between the finishing diet and dried pen manure, total gaseous N lost averaged 45% of fed N in summer and 44% of fed N in winter. These results suggest that most N is lost as NH_3 during the summer, and that NH_3 comprises about 60% of the gaseous N loss during the winter. Erickson et al (1999) used a N balance method and estimated that in Nebraska approximately 60% of fed N was lost as gaseous N during summer, and 40% during winter-spring.

Assuming that the average of summer and winter NH_3-N emission rates was representative of the mean daily emission rate throughout the year, and that the annual production of the feedyard was 100,465 head (2.25 turnovers yr^{-1}), the ammonia emission factor would be approximately 33.0 lb NH_3 $head^{-1}\ yr^{-1}$. This is slightly higher than the ammonia emission factor of 25.1 lb NH_3 $head^{-1}\ yr^{-1}$ assigned to beef cattle in drylots by USEPA (2004).

During sampling for Exp. 7 the formulation of the finishing diet at the commercial feedyard was changed and the CP concentration increased from 13.5% to 14.5%. Consequent with the increase in fed N was an increase in NH_3-N emissions. From Summer 02 (old diet) to Summer 03 (new diet), fed N increased 4,554 lb d^{-1} and ammonia emissions increased by 2,662 lb NH_3-N d^{-1}. From Winter 03 (old diet) to Winter 04 (new diet) fed nitrogen increased 3,322 lb d^{-1} and ammonia emissions increased by 2,926 lb NH_3-N d^{-1}.

During the same time period, ammonia emissions were estimated using surface isolation flux chambers (Baek et al., 2005). The ammonia emission rates determined by Baek et al. (2005) ranged from 15 to 60% of the emission rates calculated using the flux gradient, bLS, and N:P ratio methods. Because low air turnover rates in chambers can modify the microenvironment and inhibit ammonia losses from the surface (Kissel et al., 1977; Cole et al., unpublished data), and because urine spots, the primary source of ammonia losses from the pen surface (Mason, 2004; Cole, unpublished data) are rarely sampled, emission factors and flux rates determined using isolation flux chambers must be viewed with caution.

In agreement with the micrometeorological data, with the flux chamber Baek et al. (2005) noted a diurnal variation in NH_3-N flux (Figure 4) with greatest flux during the warmest part of the day. This is primarily due to a significant logarithmic relationship between manure pack temperature and NH_3-N flux (Figure 5: Baek et al., 2005). When the ammonia vapor pressure in the soil is greater than the vapor pressure of ammonia in the atmosphere, ammonia in the soil will be volatilized. Temperature is a major parameter controlling vapor pressure and thus is a major factor controlling ammonia flux from a feedlot surface.

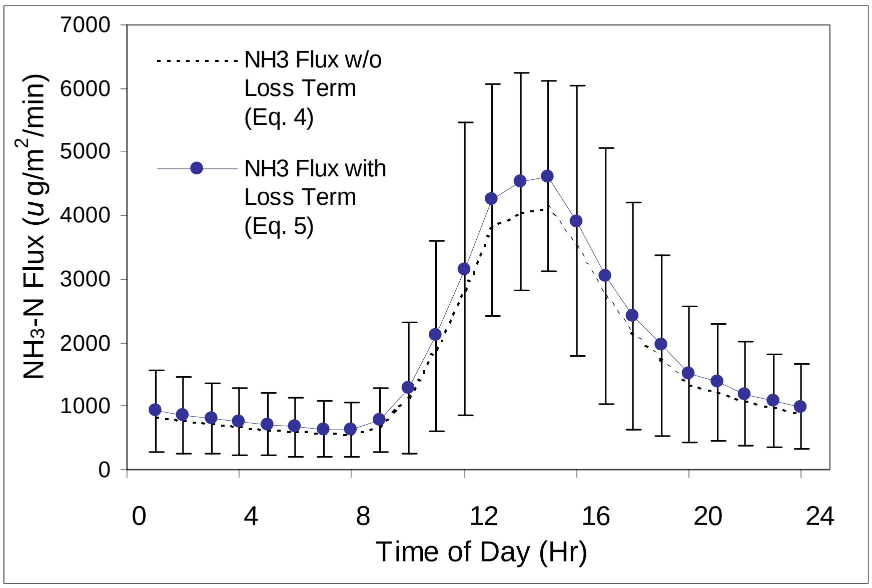


Figure 4. Daily trend of NH_3-N flux from cattle pen surface based on measured hourly means. Error bars represent one standard deviation (Baek et al., 2005).

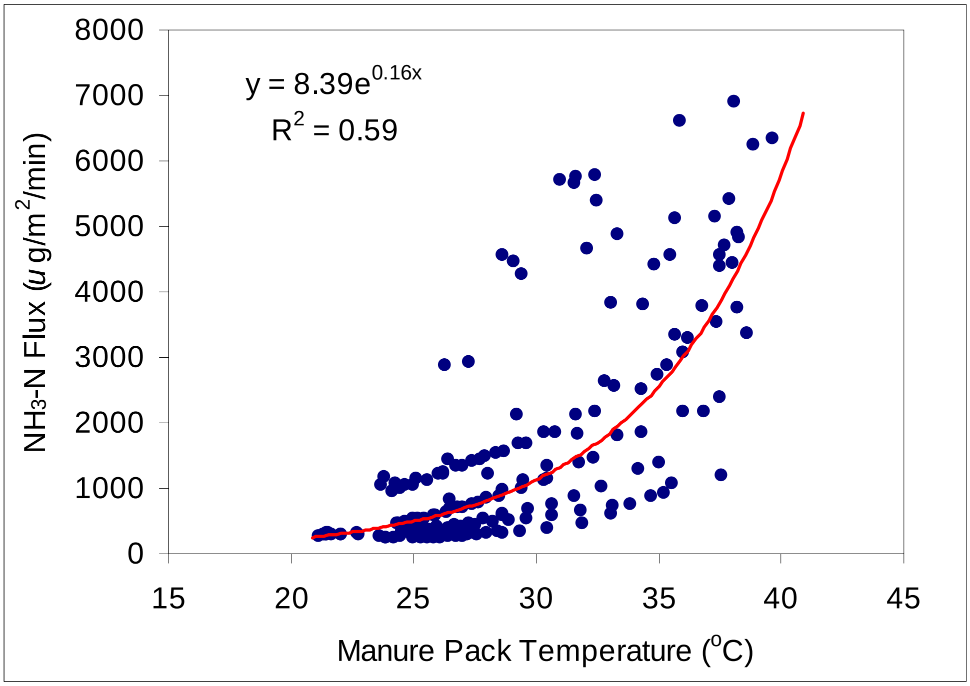


Figure 5. Hourly mean NH_3-N flux vs. the manure pack temperature (Baek et al., 2005).

Summary and Conclusions

Results of recent studies suggest that the CP requirement for optimal gain is approximately 13%; due in part to a DIP requirement of approximately 8.2%. Decreasing dietary CP concentrations to 11.5% will decrease performance by approximately % but decrease ammonia losses by approximately %. Thus, if necessary, significant reductions in ammonia emission can be accomplished with minimal effects on animal performance. Under some feed and cattle price scenarios, it may be economically feasible to decrease dietary CP concentrations to approximately 11.5%; either through the entire feeding period or during the last 56 days on feed.

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